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PRODUCTION ENGINEERING MEASURE

QUARTERLY PROGRESS REPORT NO. 2

PRODUCTION RELIABILITY IMPROVEMENT PROGRAM FOR GERMANIUM TRANSISTOR 2N1430

30 JULY 1962 TO 31 OCTOBER 1962

CONTRACT NO. DA-36-039-SC-86723

ORDER NO. 19045-PP-62-81-81

PLACED BY:

U.S. ARMY SIGNAL SUPPLY AGENCY
PHILADELPHIA, PENNSYLVANIA

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PRODUCTION ENGINEERING MEASURE

QUARTERLY REPORT NO. 2

30 JULY 1962 TO 31 OCTOBER 1962

OBJECT: To improve production techniques in order to increase the reliability and yield of the 2N1430 Germanium Transistor.

Contract No. DA-36-039-SC-86723

Order No. 19045-PP-62-81-81

Prepared by: Dennis Fallon
Henry Sivik
John Szafranski

Approved by: Ray Colucci

Approved by: Hyman Newman

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SECTION

I - ABSTRACT

Planning in all areas under study has been completed.

Equipment set-up has been completed except in those areas where refinement modifications are necessary.

Previous control production runs have been evaluated and the affected areas of study have been finalized where possible. Additional studies are or have been initiated to standardize the remaining areas of interest.

II.- PURPOSE

The purpose of this measure is to:

1. Direct efforts toward improving production techniques to improve the reliability of the 2N1430 Germanium transistor using as an objective a maximum operating failure rate of 0.05% per 1000 hours at a 90% confidence level of 25°C.

2. Improve the areas of resistivity control, etch pit control, uniform penetration in diffusion, depth control in alloying, spreading and wetting in alloying, collector attachment, surface passivation, final preparation prior to sealing, gettering technique, and leak determination in order to approach the above objective.

3. Provide information and data to demonstrate the results in the areas of study.

4. Establish and maintain quality control measures to insure accuracy and reliability of the established process techniques.

III - RELIABILITY IMPROVEMENT PROGRAM NARRATIVE

1.1 2N1430 Germanium Diffused Transistor

The 2N1430 is a military type PNP diffused alloy power transistor which was developed on U. S. Army Signal Corps Contract DA 36-039-SC-78149. (See Table I)

1.1.1 Resistivity Control - H. Sivik, F. Arden

Studies have continued on the preparation of germanium single crystal with tighter radial and vertical resistivity gradients and controlled dislocation etch pits. Resistivity and etch pit data are included on the crystals made to date.

Crystal growth was continued via the floating crucible method to control resistivity and use of the torus to control etch pits. Eight crystals were prepared in this period.

Two major mechanical failures of the floating crucible furnace permitted growing only two 1000 gram crystals. Corrosion of the water cooled bottom seal (requiring a two weeks shutdown) and breakage of both Vycor envelopes (10-12 weeks replacement) resulted in almost three months down time. However, six additional smaller crystals were made on the N. R. C. type pullers to expedite the program. Table II lists the crystals made to date and includes one production crystal for comparison.

From Table II, the vertical and radial resistivity gradients of crystals #1 thru #6 grown with the floating crucible are seen to be improved over the resistivity gradients of a typical production crystal (shown as #7) grown without the floating crucible. In three out of the 6 crystals (8 thru 13) the vertical and radial resistivity is seen to be fairly low due in some measure to the small crystal diameter. The apparent high radial gradient on crystal #10 may be partly due to defective probes on the resistivity equipment at the time of measurement.

1.1.1 Resistivity Control (cont'd)

Conclusion:

Some improvement is evident in the resistivity of crystals grown with the floating crucible. Continued effort is necessary to meet the desired goals.

Program for Next Quarter:

All major equipment has been repaired and additional crystals will be grown with effort focused on refinements of techniques and equipment.

The resistivity range will be optimized for a selected dislocation etch pit count based on results from paragraph 1.1.2 for maximum yield and improvement in product reliability.

In addition, approaches to the microwave measurement technique of material resistivity will be continued.

1.1.2 Etch Pit Control - H. Sivik

No additional runs were made with the graphite crucible cover, as described in Figure I, report No. 1 this contract, since it is believed that the torus will yield more significant results.

As is evident from Table II, crystals grown without the torus (Nos. 2, 3, 5 and 7) usually exhibit larger dislocation counts by one or two orders of magnitude than crystals grown with the torus. However, crystal Nos. 4 and 6, grown with a torus having a 1-1/2 inch I.D. hole, exhibited only about a 20% reduction in dislocations. The 3/8 inch concentric spacing between the I.D. of the hole and the O.D. of the crystal is believed to account for the higher dislocation count. In this case, the thermal pattern was only slightly changed from the pattern existing in the conventional method of crystal preparation. Thus, by a judicious selection of hole size and crystal diameter, it is hoped that the number of dislocations may be controlled. This idea will be evaluated in the near future.

Crystal Nos. 8, 10, 11, 12 and 13 consistently show a low dislocation count. Actually, the count of 100 may be too low for proper wetting and spreading (Section 1.1.5) of the solder preforms in fabricating the 2N1430 with the given temperature cycle.

Crystal No. 9 is a non-typical crystal grown with a poor seed by an uninstructed operator and should be disregarded.

A check of patents disclosed the existence of U. S. Patent #3,002,824 issued October 3, 1961 to M. P. A. Francois, which utilized an "apertured annular member" to minimize etch pits.

1.1.2 Etch Pit Control (Cont'd):

Work on this contract was started before the existence of this patent was known; nevertheless, the claims specify an "inner diameter only slightly greater than the rod diameter to be grown ---".

Conclusion:

Dislocation etch pits in Germanium single crystal can be reduced by 1 or 2 orders of magnitude by use of the torus.

Program for Next Quarter:

Trial runs will be made utilizing various dimensions of the torus (Figure I) and additional crystals will be grown in support of the current program.

A designed experiment will be conducted for the purpose of optimizing the dislocation etch pit count in order to improve product yield and enhance the overall product reliability.

1.1.3 Uniform Penetration in Diffusion - D. Fallon, J. Szafranski

Further studies were made on the potassium cyanide leaching and heat annealing methods, the oxide masking techniques, and carrier gas improvement.

A Statistical Sampling Plan to maintain the necessary control of slice thickness and parallelism has been established and is in full production use. The use of this sampling procedure has proven to be very successful. Results, thus far, indicate that 99% of the slices are within the parallelism specification and approximately 96% of the slices are within the thickness requirements. The sampling plan is of the continuous type developed by Dodge-Torrey and is referred to as CSP-3.

Continued studies of the leaching and heat annealing methods have failed to produce any noted improvement in the diffused material. All data to date show no significant changes in the finished transistor.

Studies of the oxide masking techniques have progressed favorably. A permanent furnace has been set up and the quality of the silicon dioxide layer has been improved. In conjunction with the oxide masking techniques, various geometrical configurations have been tested. In three consecutive pilot runs, utilizing material with a shallow diffused geometry, there existed an exceptional uniformity in electrical characteristics. (Table III)

In addition, Argon was studied as a carrier gas; however, no significant difference was observed in the diffused material.

Conclusion:

Inasmuch as the leaching and annealing methods have shown no significant product changes, it will be removed from consideration in regards to the current program.

1.1.3 Uniform Penetration in Diffusion (Cont'd):

Also, since all variations in diffusion techniques have provided no outstanding improvements, these processes, carrier gas, temperature time profiles, and pre-diffusion handling methods shall be considered as being standardized.

The oxide masking technique and geometry variation have provided significant improvements. These improvements include: (1) the reduced cost of material due to decrease in thickness of starting germanium slices as a result of oxide maskings: (2) the improvement in uniformity of electrical characteristics (Note the uniformity of the Ib test parameter Table III); and (3) the increase in yield as a result of geometry variation control.

Program for Next Quarter:

The oxide masking technique and geometry variation will be further studied and modified until a final process can be established.

1.1.4 Depth Control in Alloying - F. Arden

In order to provide assurance of uniform dice thickness for alloying a Statistical Sampling Approach was set up. The need for such an approach was clearly seen in light of the high volume production and the necessary controls required to yield a uniform and consistent product.

Several approaches were taken to the problem of maintaining control of dice thickness to obtain the desired electrical characteristics. Originally this dice thickness control was regulated by tightenting the specification on the final lapping of the wafers. This did not yield the desired results. Next the dice were 100% sorted by mechanical means, which also was inadequate. The net result was the statistical approach:

Statistical Study Techniques

A. Heretofore, all the dice pertaining to a single diffusion were collectoed in one or two aluminum cups after the etching operation. For the purpose of making a study, it was requested that the dice be kept in smaller fixed groups, as they were etched. The manner in which they were checked is as follows:

1. A sample of each cup of dice was checked with a micrometer (Table VI is an example).
2. Subsequently the exact distribution of sizes of the full cup of dice was ascertained (Table VII is an example).
3. The cups were identified by a letter so as to relate Table VI and VII.

1.1.4 Depth Control in Alloying (Cont'd):

B. From Table VII it is apparent that:

1. The spread of sizes from cup to cup is essentially constant.

2. The average of sizes from cup to cup varies widely.

Place all the dice together; it is easy to see that the lowest and the highest readings would be -0.2 to +1.0 (coded values) mil respectively, not counting the single readings on the periphery of the distribution. Comparing this with +0.1 to +0.5 mil (coded) required by our specification, we can see how the sizes at alloying were other than that which process specified.

Keeping the cups separated, then taking a representative sample and establishing the contents of the cup as far as size, it becomes possible to make the appropriate decision namely (1) to accept, (2) to re-etch, or (3) to screen 100%, with the help of the control chart technique.

C. From a full week's study of 10 amp DAP transistors, the standard deviation of a cup of X number of dice was estimated at 0.132 mils. An examination of a normal curve (Figure III) reveals that, with our present specification, if we keep the average of a cup at +0.3 mils, approximately 87% of the contents of the cups will be between +0.1 and +0.5 mils. This percentage is satisfactory.

It is well known that the standard deviation of a sample is related to the standard deviation of the population by $\sigma_{\bar{X}} = \sigma / \sqrt{n}$ where:

$\sigma_{\bar{X}}$ = Standard deviation of the mean of a sample of size n.

σ = Standard deviation of the population.

n = Size of the sample (in our case 10 was chosen for practical reasons).

1.1.4 <u>Depth Control in Alloying</u> (Cont'd):

For our case we find:

$$\sigma_{\bar{X}} = 0.132/\sqrt{10} = 0.041$$

3 sigma limits are $+0.3 \pm 0.123$ which gives upper and lower limits on the sample

The sample average = 0.3 mil

Upper limit on sample average = $0.3 + 0.123$ mils = 0.42 mil

Lower limit on sample average = $0.3 - 0.123$ mils, (Figure IV) = $+0.18$ mil

On an $\bar{X}$ (average) and R (range) chart we also obtain limits for the range. From any quality control handbook we can obtain 99% upper limit for the range. However, we have only 87% confidence for our average, and, therefore, we shall correspondingly reduce the limits on the range to 0.5 mil.

The following is a summary of our sampling plan:

1. Do not mix the cups of dice, as etched.
2. Take a sample of 10, per cup.
3. Calculate average and range.
4. If range is larger than 0.5 mil, screen cup 100%.
5. Given that the range is 0.5 mil or less,
    a. If the average is between 0.18 and 0.42 mil, accept the cup.
    b. If the average is larger than 0.42 mil, re-etch cup and re-submit.
    c. If the average is below 0.18 mil, screen 100%.

With this plan we would expect approximately 87% of the dice to be between the 0.1 to 0.5 mil limits. A control chart is shown, which the operator uses to make the decision on a particular lot. The areas of 100% screen, accept and re-etch should be noticed.

III. RELIABILITY IMPROVEMENT PROGRAM (CONTINUED)

1.1.4 Depth Control in Alloying (Cont'd):

The benefits of the plan are:

1. Efficient application of the control chart technique will tend to largely eliminate the need for mechanical gaging of the DAP dice 100%, thus all but eliminating one operation, and effecting operator savings.
2. Handling of the dice will considerably reduced.
3. The distribution of the dice will be centered at 0.3 mil as desired, rather than as tolerated at present, eliminating the necessity of excessive number of alloy schedules.

Conclusion:

No sampling plan can give 100% assurance of making the correct decision. When we make a decision with, say, 90% confidence we are indicating, in fact, that we expect to make 10 erroneous decisions out of 100, in the long run. Keeping this in mind we may rely on the control chart technique to give satisfactory results with acceptable risks.

The results show that dice with better thickness control are being made available to the alloying operation. This in turn will contribute to a more uniform end-product distribution and directly affect the product yield and reliability.

Program for Next Quarter:

The above sampling plan is in full use in production and will continually be monitored as outlined.

III. RELIABILITY IMPROVEMENT PROGRAM NARRATIVE (CONTINUED)

1.1.5 Spreading and Wetting in Alloying

As the depth control and alloying is also affected, it will be necessary in all cases to consider spreading and wetting in alloying in conjunction with "1.1.4 Alloy Depth Control in Alloying" since depth penetration in surface spreading are closely dependent on one another.

III - RELIABILITY IMPROVEMENT PROGRAM NARRATIVE (CONTINUED)

1.1.6 Collector Attachment - D. Fallon

Efforts were made during this period to reduce the thermal resistance value.

Using the standard ultrasonic monnting technique (Figure II) units were processed on platforms with and without the mounting boss. The data on the resultant units (Table V) show both a decrease in the average thermal resistance value for the elements mounted on the bossless platform as well as a smaller variation in the over-all distribution.

Conclusion:

The bossless platform shows an improvement in thermal resistance with center of distribution at 1.10^{o}C/W (measured junction to heat sink).

Program for Next Quarter:

During this period a large quantity of bossless platforms shall be processed to substantiate the initial data. At the same time these units shall also be evaluated to observe mechanical characteristics. The prime effort this quarter will be to finalize the collector attachment techniques.

III - RELIABILITY IMPROVEMENT PROGRAM NARRATIVE (CONTINUED)

1.1.7 Surface Passivation and Final Preparation Prior to Sealing

The present production techniques have been finalized.

(See Quarterly Report No. 1)

1.1.8 Gettering Techniques - D. Fallon

During this period, further efforts were directed toward improvements in the processing of the molecular sieve powder.

Results of the finished product continued to demonstrate (as indicated in the First Quarterly Report, Table VI) that the units processed with the molecular sieve pellet appeared better than those with the powder.

A glass type desiccant pellet was also processed and compared to the molecular sieve pellet. Results (Table IV) show no significant differences.

Conclusion:

Neither the powder nor the glass desiccant shows an improvement over the molecular sieve pellet. After 10,000 hours storage life at 110°C, Quality Control's "Lot Control System" indicates that units fabricated with the molecular sieve pellet show a general stabilization in the Icbo test parameter. This is a good indication that the moisture content in the transistors is well controlled.

Program for Next Quarter:

During this period, a zinc compound, which has been successfully used on smaller germanium devices shall be evaluated on the 10 amp DAP transistor. All efforts shall be made to finalize gettering methods.

1.1.9 Leak Determination - E. Yurowski

A test is presented which has been used for determining the leak rate of the standard production 2N1430 transistor. It can be seen that the majority of devices subjected to this test exhibit an exceedingly small leak rate.

Thirty-five (35) electrically "good" 10 amp DAP transistors were selected for evaluation. Extreme care was taken to prevent contamination of the samples. Samples selected were first examined with a 20X microscope to assure that the devices were free of any dirt, grease, branding or excessively cracked glass. This precaution was taken to minimize the possibility of helium absorption by matter adhering to the outer surfaces of the samples. Throughout the experiment, nylon gloves were worn by the technician handling the units. Devices were air-washed with pressurized house air. The chamber was carefully cleaned and a clean cardboard liner was placed on the bottom of the tank. Devices were put into the vacuum-pressure tank, the seal was greased with Consolidated Vacuum Corp., Celvacene 776 vacuum grease and the lid tightly secured. The chamber was then evacuated to a pressure of 1 mm Hg (approximately 150,000 feet altitude) and operated at that pressure for a period of 30 minutes. Then, without allowing any air into the chamber, the vacuum pump was shut off and helium at 90 psi was injected into the chamber. The intent here was to evacuate some portion of the gaseous matter that may have entered a leaking transistor and to force helium back into the cavity.

1.1.9 Leak Determination (cont'd):

After 4 hours at 90 psi, the units were removed and immediately spray-washed with nitrogen to remove any helium molecules adhering to the transistor surfaces. Within 30 minutes of removal of the samples from the back-filling chamber all devices were helium leak tested. All thirty-five (35) units were placed in a brass receptacle and tested as a lot on the mass spectrometer. As soon as the test was initiated the machine kicked off, due to overload, that is, an excessive helium leak (greater than 1.0×10^{-4}) was detected. The lot was then withdrawn from the receptacle and divided into three groups of 10 each and 1 group of 5. The test results are as shown in Table IX.

It should be noted that both groups 2 and 3 indicated evidence of helium leaks. However, when the devices were tested individually only one defect was found. An explanation of the reading on group 2 is that the receptacle was not pumped down completely and some helium absorbed by the outer surfaces of the devices caused a false indication. If the leak detector was allowed to pump for an additional moment or two the reading would have decreased to approximately 3.0×10^{-9} (level of other non-leaking lots).

Although the readings indicated in Table IX appear to be "absolute" numbers, they are not, since measurements in the area of 10^{-9} and 10^{-10} are "apparent" and not consistently repeatable. It can be assumed, however, that devices giving leak-rate readings of 10^{-9} and 10^{-10} are not leakers by this criterion, but rather the reading is due to minute quantities of helium remaining in the test receptacle.

1.1.9 Leak Determination (cont'd):

Calculation of leak-rates shown in Table IX was as follows:

$$\text{Unknown leak rate} = \frac{K \times R}{A} \cdot 10^{-5}$$

K = Sensitivity Calibrator leak rate

A = Actual observed reading of Sensitivity Calibrator

R = Reading of unknown leak

The single unit that indicated a high leak rate was re-tested utilizing a single unit adapter. The leak rate observed was confirmed and found to occur through the glass seal. Reversing the unit in order to check the dome seal indicated no leak. Further tests by the detergent bomb method additionally confirmed that the unit was defective since comparison of before and after detergent test data indicated an increase in Icbo at 100V.

The back-filling test chamber provides a lot test capability in the area of several thousand pieces every 4-1/2 hours. The rate at which the complete test could be performed depends on the percent of defective product introduced.

Conclusion:

Test results indicated that the test is effective and can be adopted to high volume production. No damage occurs to the transistors, since the domes are not punctured. Although in this test, extreme examples of high (greater than $1 \cdot 10^{-4}$) cc He/sec.) and low (less than $1 \cdot 10^{-10}$ cc He/sec.) leakage rates were detected, it can be expected that the equipment will also accurately detect leakage rates of intermediate values. The technique developed will allow high volume testing should this be required for the purpose of removing questionable hermetically sealed transistors.

1.1.9 Leak Determination (Cont'd):

Program for Next Quarter:

At this point, the minimum repeatable leak rate has not been determined. Additional tests are now in process.

IV - IDENTIFICATION OF PERSONNEL

1.1 Personnel

The following changes were made during this period:

Added to contract:

Henry, Peter

Labriola, Carmine

Yurowski, Edmund

Deleted from contract:

Caldwell, Dr. Wallace C.

Candia, Joseph

Gray, Donald E.

Status change:

NEWMAN, HYMAN - Chief Engineer, Bendix Semiconductor Division, will assume the responsibilities for the management planning, scheduling, implementation, and evaluation of the entire project.

HENRY, PETER

Lafayette College	B.S. Biology 1952
Monmouth College	B.S. Chemistry 1961

Mr. Henry is a Project Engineer, Bendix Semiconductor Division, and is responsible for the production engineering of the 10 amp DAP transistor. Since joining Bendix in 1957, he has done development work on surface physics and has contributed many techniques in the use of chelates. Prior to joining Bendix he was employed in chemical research work for the Celanese Corporation.

IV - IDENTIFICATION OF PERSONNEL (CONTINUED)

1.1 Personnel (Cont'd):

LABRIOLA, CARMINE

Pratt Institute	1939 - 1940
Seton Hall College	1947 - 1949

Mr. Labriola is a Jr. Engineer, Bendix Semiconductor Division, and is responsible for diffusion and post-diffusion processing of germanium DAP transistors. Upon joining Bendix in 1956 he assisted in the development and set-up of germanium crystal growing and the reclamation of germanium through zone-refining methods. From 1957 to 1959 he assisted in the development of the diffused base transistor and was then assigned to production engineering.

YUROWSKI, EDMUND

Pratt Institute	1953 - 1955	
Lafayette University	1955 - 1956	
Penn State University	1959	B.S.E.E.
Rutgers University	1956 - 1957	Post graduate work

Mr. Yurowski is currently supervisor of Reliability and Quality Assurance and is responsible for new product evaluation, reliability testing programs, product qualification and final product acceptance. From 1959 to 1961 Mr. Yurowski was Chief Quality Control Test Engineer at Philco Corp., Lansdale Division. From 1955 to 1959 Mr. Yurowski was associated with Tung-Sol Electric, Inc. as manager of Reliable Tube Quality Control. His service experience with the U.S. Navy included one year of electronics training at Great Lakes, Illinois and three years of radar and communications repair.

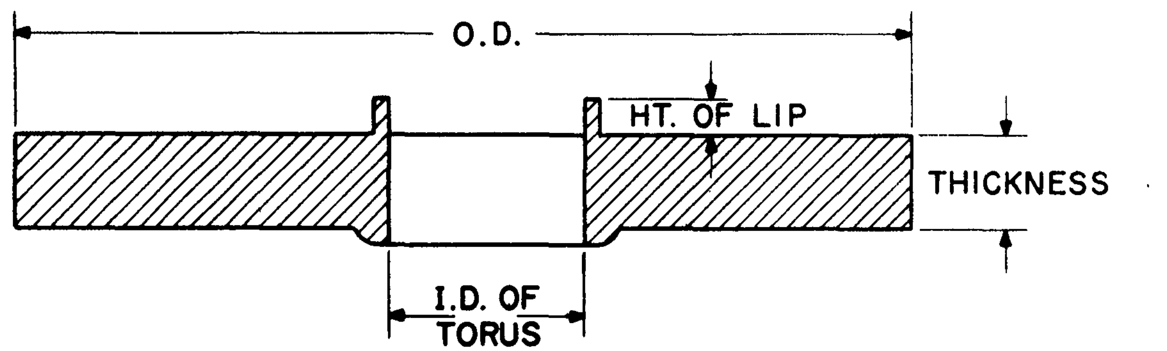
IV - IDENTIFICATION OF PERSONNEL (CONTINUED)

1.2 Engineering Time

During this period 952 hours were spent by Bendix personnel toward the fulfillment of the contractual commitments.

FIGURE I

TORUS CROSS-SECTION



DIMENSIONS IN INCHES

DESIGNATION	O. D.	I. D. OF HOLE	HT. OF LIP	THICKNESS
A	2-5/8	1-3/16	3/8	3/8
B	2-5/8	1	1/2	1/4
C	3-5/16	1-1/2	3/32	5/16
D	2-15/16	1-1/2	3/32	1/4

ULTRASONIC MOUNTING STAND

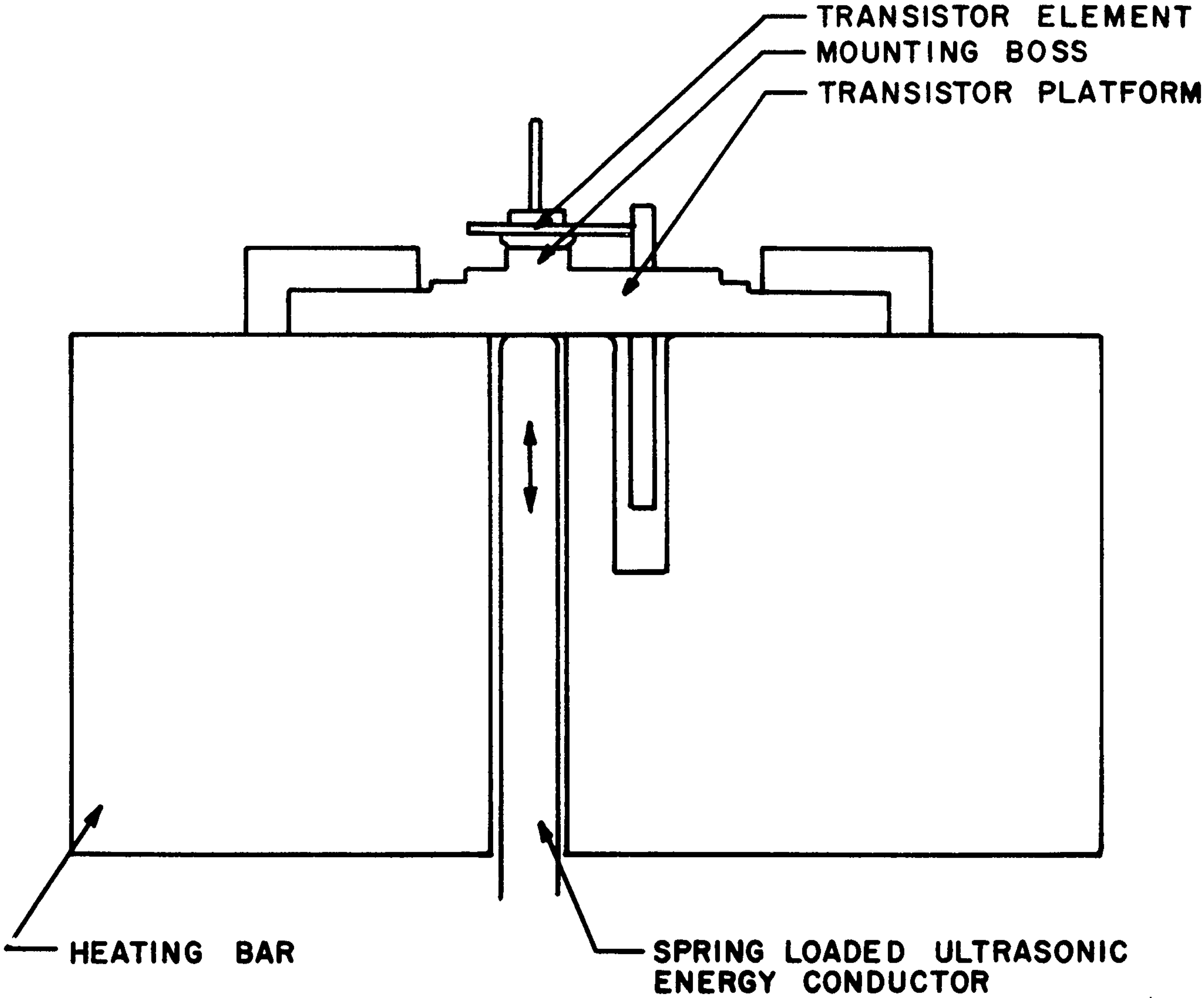
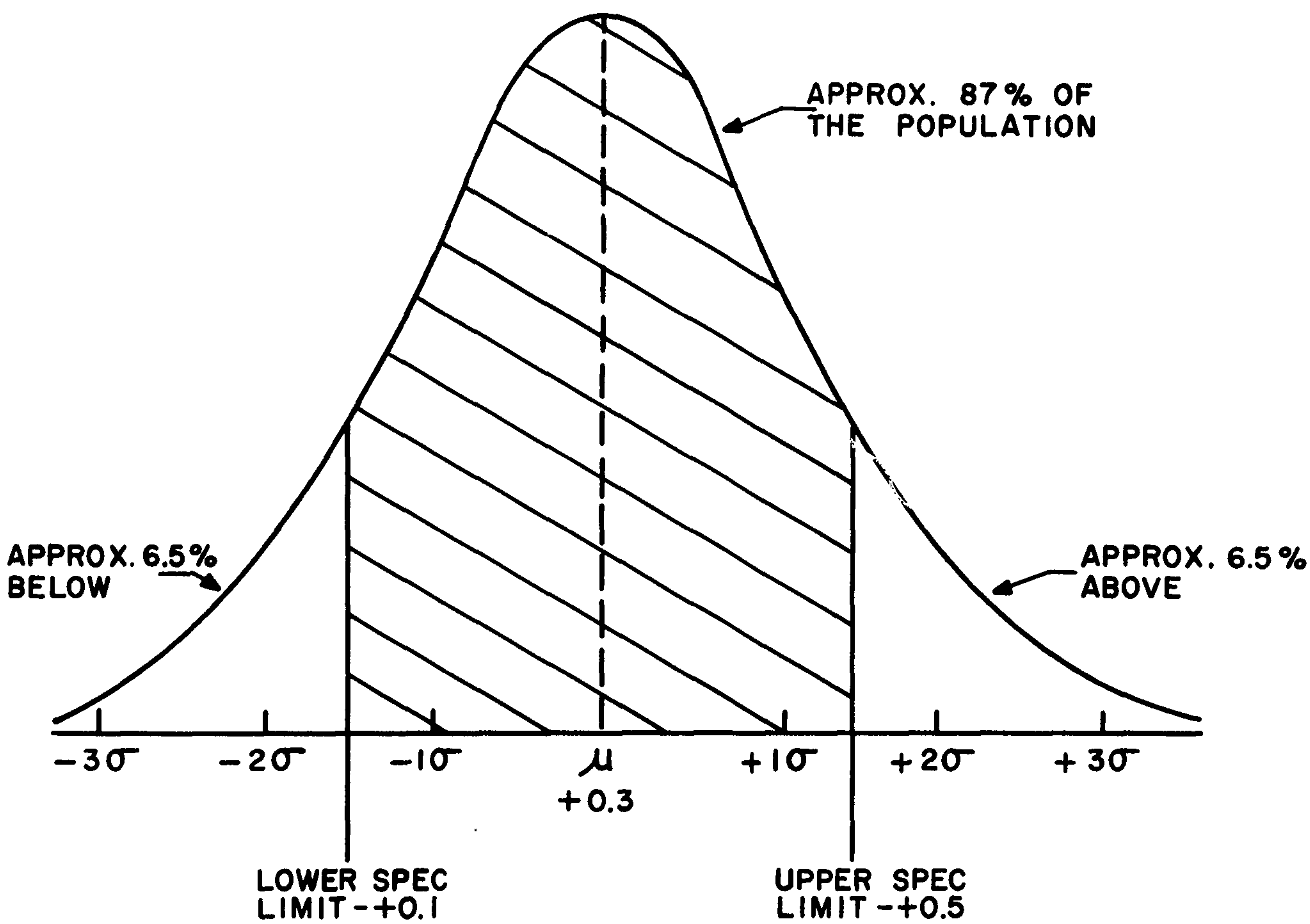


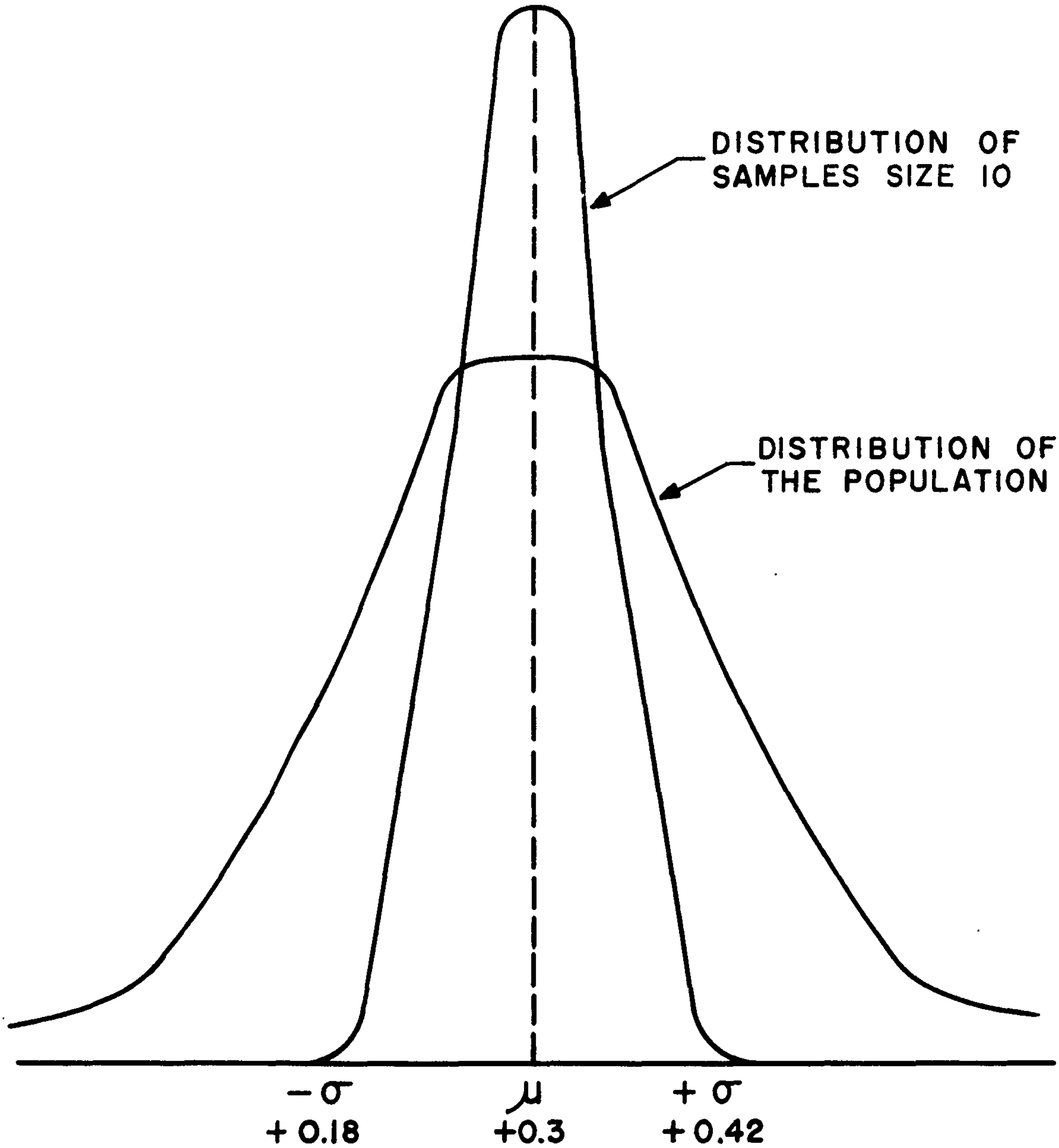
FIGURE II

FIGURE III
STATISTICAL STUDY



σ — STANDARD DEVIATION OF POPULATION
μ — AVERAGE OF THE POPULATION

FIGURE IV
STATISTICAL STUDY



σ — STANDARD DEVIATION OF POPULATION
μ — AVERAGE OF THE POPULATION

TABLE I
2N1430
TEST SPECIFICATIONS

				LIMITS				TEST CONDITIONS								
								V_{CB}	V_{CE}	I_E	I_B	R_{BE}	V_{CC}	T	V_{EBO}	f
LINE	TESTS	% AQL	SYMBOL	MIN.	MAX.	UNIT	NOTES	Vdc	Vdc	Adc	Adc	OHMS	Vdc	°C	Vdc	kc
1	Collector Cutoff Current	1.0	I_{CBO}		-300	µAdc		-1.5						25		
2	Collector Cutoff Current	1.0	I_{CBO}		-50	mAdc		-100						25		
3	Emitter Cutoff Current	1.0	I_{EBO}		-50	mAdc								25	-1.5	
4	Collector Current	1.0	I_{CEO}		-100	mAdc			-40			∞		25		
5	Collector Current	1.0	I_{CER}		-50	mAdc			-80			100		25		
6	Base Current	1.0	I_B	-50	-165	mAdc			-2.0	5.0				25		
7	Base Current	1.0	I_B		-500	mAdc			-2.0	10				25		
8	Base Voltage	1.0	V_{BE}		-0.9	Vdc			-2.0	10				25		
9	Collector Saturation Volt.	1.0	$V_{CE(S)}$		-0.75	Vdc				10	-1.0			25		
10	Current Gain	4.0	h_{fe}	7.5					-6.0	50				25		100
11	Rise Time	4.0	t_r		5	µsec				5.0			-28	25		
12	Fall Time	4.0	t_f		2	µsec				5.0			-28	25		
13	Thermal Resistance	4.0	θ_r		1.5	°C/W	1									
14	Base Current	4.0	I_B	-50	-165	mAdc			-1.5	5.0				80		
15	Life Test (storage)						2									

RATINGS ABS. MAX. (at 25 °C)

SYMBOL	MAX.	UNIT
V_{CB}	-100	Vdc
V_{CE}	-40	Vdc
V_{EB}	-1.5	Vdc
I_C	-10.0	Adc
PC	50	W
T_j	+100	°C
T storage	+100	°C

MIL. SCL-7002/25A

NOTES:

1. Junction to mounting base.
2. 1000 hours at 100° C.

Life Test 1000 hrs. End Points

SYMBOL	COND.	MAX.	UNIT
I_{EBO}	Line 3	-75	mAdc
I_{CBO}	Line 2	-75	mAdc
I_B	Line 7	-625	mAdc

TABLE II
CRYSTAL DATA (1.1.1)

NO.	CRYSTAL IDENTI-FICATION	FURNACE	TOP READING	BOTTOM READING	% GRADIENT # RADIAL Top Reading	% GRADIENT + VERT Per inch of crystal	* TORUS NO.	ETCH$_2$ PITS / cm TOP-BOTTOM	CRYSTAL LENGTH IN.	CRYSTAL DIAM. IN.	REMARKS
1	4 RA	Fl. cruc.	9.0-6.0	3.0-2.2	20	9.6	none	N. D.	10	1	
2	19 RA	"	3.8-3.2	2.5-2.2	8.6	3.3	"	4700 top	12	1-1/8	
3	21 RA	"	4.0-2.0	2.9-1.0	33	4.3	"	3100-6300	10	1	
4	47 RA	"	2.0-1.5	2.0-1.5	14	0	C	1800-3700	14	5/8-1/2	1-1/2 diam. hole in torus
5	71 RA	"	4.5-4.0	3.5-3.0	5.9	2.2	none	over 6000	12	7/8-1	
6	BDX-4	" Bendix type FCE	3.5-3.0	2.5-2.0	6.7	6.0	D	3000-2700	6	3/4	1-1/2 diam. hole in torus
7	80 EJ	NRC single cruc.	18-13	12-10	16	5.0	none	over 5000	6	7/8	Typical production crystal
8	141	"	15-14	8.0-5.0	3.5	12.6	B	100-200	6	1/2	Long good seed; grown in production furnace
9	GG	"	4.4-3.8	1.6-1.0	7.3	16	B	1800-2100	6-1/2	1/2	Short poor seed; grown in production furnace, 1-1/2 hole in torus
10	212X	"	42-32	38-28	13.5	2.1	A	50-100	5-1/2	13/16	Engr. lab. furnace
11	217X	"	4.9-4.1	4.1-3.4	8.4	3.6	A	50-100	5	11/16	" " "
12	222X	"	3.2-2.7	2.0-1.8	8.5	7.9	A	1-16	5-1/2	9/16-3/4	" " "
13	230X	"	12.6-11.1	10.9-9.0	15	2.7	A	50-50	5-1/2	1/2	" " "

% Radial Gradient $= \frac{T - t}{T + t} \cdot 100$

+ % Vertical Gradient $= \frac{2\left[(T + t) - (B + b)\right]}{(T + t) + (B + b)} \cdot \frac{100}{L}$

Where:

B = high bottom ρ T = high top ρ L = length of crystal

b = low bottom ρ t = low top ρ

* See Figure I for explanation of torus No.

TABLE III
DIFFUSED PENETRATION CONTROL (1.1.3)

	ICBO VCB = 2V			BVCEO IC = 0.5A			IB VCE = 2V IC = 12A			BVEBO IE = 50ma			ICBO VCB = 100V		
UNIT NO.	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
	μa	μa	μa	V	V	V	ma	ma	ma	V	V	V	ma	ma	ma
1	63	48	50	116	100	166	235	210	520	6.9	10.6	4.0	0.31	0.07	0.09
2	55	51	56	96	116	130	245	220	820	5.0	5.7	2.8	0.32	0.17	0.14
3	48	55	50	122	158	134	235	700	340	6.6	4.8	3.6	0.14	0.80	0.10
4	60	38	S	160	104	S	615	230	S	2.5	5.5	3.0	0.48	0.07	S
5	48	54	55	108	152	142	165	330	340	6.5	4.9	2.6	0.29	0.12	0.25
6	80	40	67	102	140	36	225	320	590	6.3	4.9	3.5	1.50	0.05	0.17
7	62	40	53	86	120	28	165	210	275	9.1	5.9	3.8	2.20	0.11	0.18
8	58	50	58	106	114	70	235	200	300	9.5	7.9	3.5	0.55	0.08	1.90
9	68	44	48	136	132	142	355	220	600	10.0	6.4	4.7	0.23	0.20	1.00
10	62	50	43	S	92	134	565	300	500	5.7	8.3	3.6	S	0.35	0.10
11	38	36	48	110	100	106	235	200	350	4.0	5.9	2.7	0.31	0.05	0.70
12	48	47	50	108	112	128	275	330	390	8.1	6.3	3.1	0.70	0.09	3.00
13	64	63	50	116	104	OSC	355	200	820	6.5	6.3	3.2	0.26	6.40	2.00
14	70	75	47	136	S	148	285	590	600	7.2	6.4	3.6	0.25	S	0.50
15	53	51	48	98	130	96	235	230	260	6.6	5.7	3.2	0.90	0.14	10.0
16	49	190	50	96	100	142	205	210	400	4.6	8.0	3.2	1.60	0.60	0.15
17	63	47	46	102	120	72	165	205	265	8.8	6.2	3.2	0.39	0.29	0.15
18	58	38	53	112	80	OSC	365	400	1250	6.9	4.7	2.2	0.85	5.70	0.09
19	64	39	57	46	122	O	215	330	O	7.8	6.7	O	2.00	0.10	0.37
20	53	40	51	112	102	144	265	140	300	7.4	6.3	3.3	0.24	0.10	0.09
21	53	41	58	102	104	156	295	180	860	6.8	8.2	O	1.80	0.05	0.09
22	48	40	62	66	96	38	175	160	380	7.2	5.6	3.0	1.30	0.10	0.10
23	48	42	82	118	125	OSC	345	300	690	4.1	6.8	3.5	0.37	0.07	1.00
24	88	700	70	S	S	124	1600	290	320	6.1	5.1	4.1	S	S	0.21
25	58	47	200	132	102	144	335	230	1200	5.9	6.5	3.7	0.50	0.73	0.34
26	70	60	37	110	122	116	165	220	290	5.3	6.2	3.4	0.65	0.15	0.09
27	120	60	51	S	56	62	265	190	630	5.7	5.6	2.6	S	S	0.15
28	67	40	52	122	86	80	275	170	210	3.8	8.3	3.0	1.70	0.16	0.13
29	54	42	47	116	124	156	365	180	680	7.8	6.2	2.7	1.20	0.07	0.24
30	180	58	59	S	S	124	365	220	310	8.0	6.7	4.2	S	S	0.23

GROUP A - GEOMETRY VARIANCE USING LAPPING METHODS
GROUP B - GEOMETRY VARIANCE USING ETCHING METHODS
GROUP C - PRESENT PRODUCTION GEOMETRY

NOTE: ABOVE UNITS ARE RAW STARTS FROM ALLOYING

SYMBOLS: S = SHORT O = OPEN O.S.C. = SECONDARY BREAKDOWN OSCILLATION

TABLE IV
DESICCANT EVALUATION (1.1.8)

UNIT NO.	ICBO VCB = 1.5V A	B		ICER VCE = 80V RBE = 100Ω A	B		IB VCE = 2V, IC = 10A A	B
	μa	μa		ma	ma		ma	ma
1	52	64		0.2	0.2		150	190
2	46	59		0.1	0.8		210	170
3	37	67		0.2	0.8		200	125
4	52	61		A	0.8		150	225
5	43	50		0.1	0.1		180	210
6	45	46		1.0	0.1		205	230
7	56	53		0.3	0.2		160	230
8	52	60		0.1	0.1		225	210
9	66	63		A	0.1		225	275
10	47	54		0.1	0.1		180	175
11	53	65		0.6	1.4		250	150
12	52	47		0.1	0.1		190	240
13	85	72		0.4	0.1		150	190
14	53	55		3.0	0.1		170	220
15	42	61		0.1	0.1		150	200
16	45	64		0.2	0.8		240	220
17	45	58		0.1	3.5		145	120
18	60	46		0.3	2.0		180	170
19	45	54		0.1	0.1		125	290
20	51	57		0.1	A		120	190
21	52	49		0.2	0.1		210	160
22	54	59		0.2	0.3		160	270
23	55	39		0.1	3.5		240	175
24	61	52		0.1	0.1		220	180
25	44	58		0.7	0.4		190	180

GROUP A = GLASS DESICCANT PELLET

GROUP B = MOLECULAR SIEVE PELLET

TABLE V
TO-3 PLATFORM EVALUATION (1.1.6)

EX. NO. 13 UNIT NO.	ICBO VCB = IV A	ICBO VCB = IV B	BVCEO IC = 0.5A A	BVCEO IC = 0.5A B	θ_R A	θ_R B
	μa	μa	V	V	°C/W	°C/W
1	57	63	134	130	1.03	0.93
2	57	48	110	105	0.97	1.07
3	59	62	144	108	1.03	1.20
4	59	61	114	95	1.07	1.16
5	54	57	110	145	1.11	1.07
6	49	46	104	110	1.07	1.16
7	39	68	95	120	1.03	1.03
8	54	57	114	110	1.20	1.09
9	36	69	110	145	1.24	1.30
10	40	63	130	100	1.10	1.39
11	56	54	110	135	1.11	1.20
12	48	50	140	120	1.20	1.01
13	69	57	120	105	1.30	1.20
14	56		114		0.93	
15	72		95		1.09	
AVERAGE VALUE					1.10	1.14

GROUP A - BOSSLESS PLATFORM

GROUP B - STANDARD PLATFORM

θ_R MEASURED JUNCTION TO HEAT SINK

TABLE VI
SAMPLE INSPECTION AFTER ETCH (I.I.4)

VARIATION OF DIE THICKNESS (CODED)

CUP NUMBER	DIE NUMBER 1	2	3	4	5	6	7	8	9	10
A	0.1	0.3	0.3	0.5	0.3	0	0.3	0.4	0.3	0.3
B	0.8	0.4	0.7	0.7	0.7	0.8	0.7	0.9	0.6	0.8
C	0.5	0.2	0.1	0.5	0.6	0.7	0.4	0.8	0.4	0.4
D	0.4	0.3	0.3	0.5	0.3	0.3	0.4	0.3	0.3	0.1
E	0.8	0.7	0.4	0.5	0.3	0.3	0.7	0.5	0.3	0.3
F	0.3	0.6	0.5	0.6	0.5	0.3	0.2	0.5	0.5	0.3
G	0.2	0.2	0	0.3	0	0.2	0.2	-0.2	0.4	0.2
H	0.1	0.1	0.6	0	0	-0.1	0.1	0	0.2	0
I	0.6	0.5	0.6	0.5	0.5	0.9	0.6	0.7	0.7	0.6
J	0.6	0.5	0.4	0.6	0.4	0.7	0.7	0.6	0.4	0.7
K	0	0	0.2	0.3	0	0.1	0.1	0.2	-0.1	0
L	0.5	0.5	0.4	0.3	0.3	0.5	0.4	0.4	0.4	0.4
M	0.6	0.5	0.7	0.6	0.2	0.6	0.6	0.9	0.8	0.4
N	0.2	-0.1	0	0.1	0	0	0.2	0	0.1	-0.1
O	0.8	0.8	0.6	0.8	0.5	0.9	0.8	0.6	0.6	0.4
P	0.5	0.8	1.0	0.9	0.6	0.5	0.9	0.7	0.7	0.5
Q	0.5	0.5	0.3	0.5	0.8	0.5	0.5	0.4	0.4	0.8
R	0.2	0.2	0.1	0.2	0.6	0.4	0.4	0.3	0.3	0.5
S	0.3	0.4	0.3	0.3	0.4	0.1	0.2	0.6	0.7	0.3
T	0.4	0.3	0.3	0.3	0.4	0.5	0.3	0.3	0.8	0.3
U	0.3	0.4	0.5	0.6	0.4	0.6	0.5	0.4	0.6	0.3
V	0.6	1.0	0.9	0.7	0.4	0.7	0.5	0.6	0.6	0.7
W	0.2	0.1	0	0	0	0.2	0	0	0.1	-0.1
X	0.4	0.3	0.3	0.5	0.6	0.3	0.5	0.4	0.5	0.2

All values are positive except as indicated.

TABLE VII
100% INSPECTION AFTER ETCH (1.1.4)

FREQUENCY DISTRIBUTION PER CUP

CUP NUMBER	DIE THICKNESS (CODED)														
	-0.2	-0.1	0	+0.1	+0.2	+0.3	+0.4	+0.5	+0.6	+0.7	+0.8	+0.9	+1.0	+1.1	+1.2
A			2	3	9	26	8	8	2	1					
B						2	1	3	9	18	14	8			
C				2	3	7	14	12	13	4	1	1	1		
D				1	2	14	10	13	8	5	4				
E					2	10	13	20	5	7	3				
F				1	8	8	19	14	9	1					
G	1		12	8	20	11	6	2	1						
H	1	7	16	14	12	3	3	1	1						
I							2	6	17	13	15	5	1		
J						2	8	16	20	9	3	1	1		
K	1	5	20	16	6	8	1								
L				2	11	15	16	8	5		1				
M					3	5	5	10	16	9	7	3			
N	3	13	15	17	9					1					
O							7	10	10	10	14	6	1		
P				1			3	13	10	18	11	3	1		
Q				1	9	14	13	17	1	1	2	1			
R			1	10	13	19	10	4	2						
S			1	6	5	14	11	9	8	3					
T			2	4	6	14	12	11	6	1	2				
U				1	2	6	12	17	14	3	2			1	
V							3	8	14	14	12	6	1		1
W	1	7	16	20	5	6	1								
X			1	1	2	12	18	16	4	2					

TABLE VIII
CONTROL CHART INSPECTION SHEET (1.1.4)

PRODUCT: 10A DAP DICE F2-63

CHARACTERISTIC: THICKNESS

TEST CONDITIONS: AFTER ETCH

MEAS. INSTRUMENT: MICROMETER

UNIT OF MEAS: MIL

SPEC. LIMITS: AVG 0.18 - 0.42

SAMPLE NO.		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
SUMMARY	AVERAGE $\bar{X}$ (OR TOTAL)	0.28	0.71	0.46	0.32	0.48	0.43	0.15	0.10	0.62	0.56	0.08	0.41	0.59	0.04	0.68	0.71	0.52	0.32	0.36	0.34	0.46	0.67	0.05	0.40
	RANGE R	0.5	0.5	0.7	0.4	0.5	0.4	0.6	0.7	0.4	0.3	0.4	0.2	0.7	0.3	0.5	0.5	0.5	0.5	0.6	0.5	0.3	0.6	0.3	0.4

NOTE: For individual coded readings see TABLE VI

TABLE IX
LEAK RATE EVALUATION (1.1.9)

GROUP		1	2	3	4
QUANTITY		10	10	10	5
GROUP READING		2.9×10^{-9}	1.0×10^{-6}	OVERLOAD	2.9×10^{-9}
INDIVIDUAL READINGS	1	7.0×10^{-9}	2.0×10^{-9}	5.5×10^{-10}	9.2×10^{-10}
	2	7.0×10^{-10}	1.1×10^{-9}	3.7×10^{-10}	1.3×10^{-9}
	3	7.0×10^{-10}	2.2×10^{-9}	9.2×10^{-10}	1.8×10^{-9}
	4	7.0×10^{-10}	2.6×10^{-9}	9.2×10^{-10}	1.8×10^{-9}
	5	7.0×10^{-10}	1.8×10^{-9}	9.2×10^{-10}	1.8×10^{-9}
	6	7.0×10^{-10}	1.3×10^{-9}	OVERLOAD	
	7	1.3×10^{-9}	2.2×10^{-9}	1.4×10^{-9}	
	8	1.8×10^{-9}	1.1×10^{-9}	9.2×10^{-10}	
	9	7.0×10^{-10}	9.2×10^{-10}	9.2×10^{-10}	
	10	1.3×10^{-9}	1.1×10^{-9}	9.2×10^{-10}	

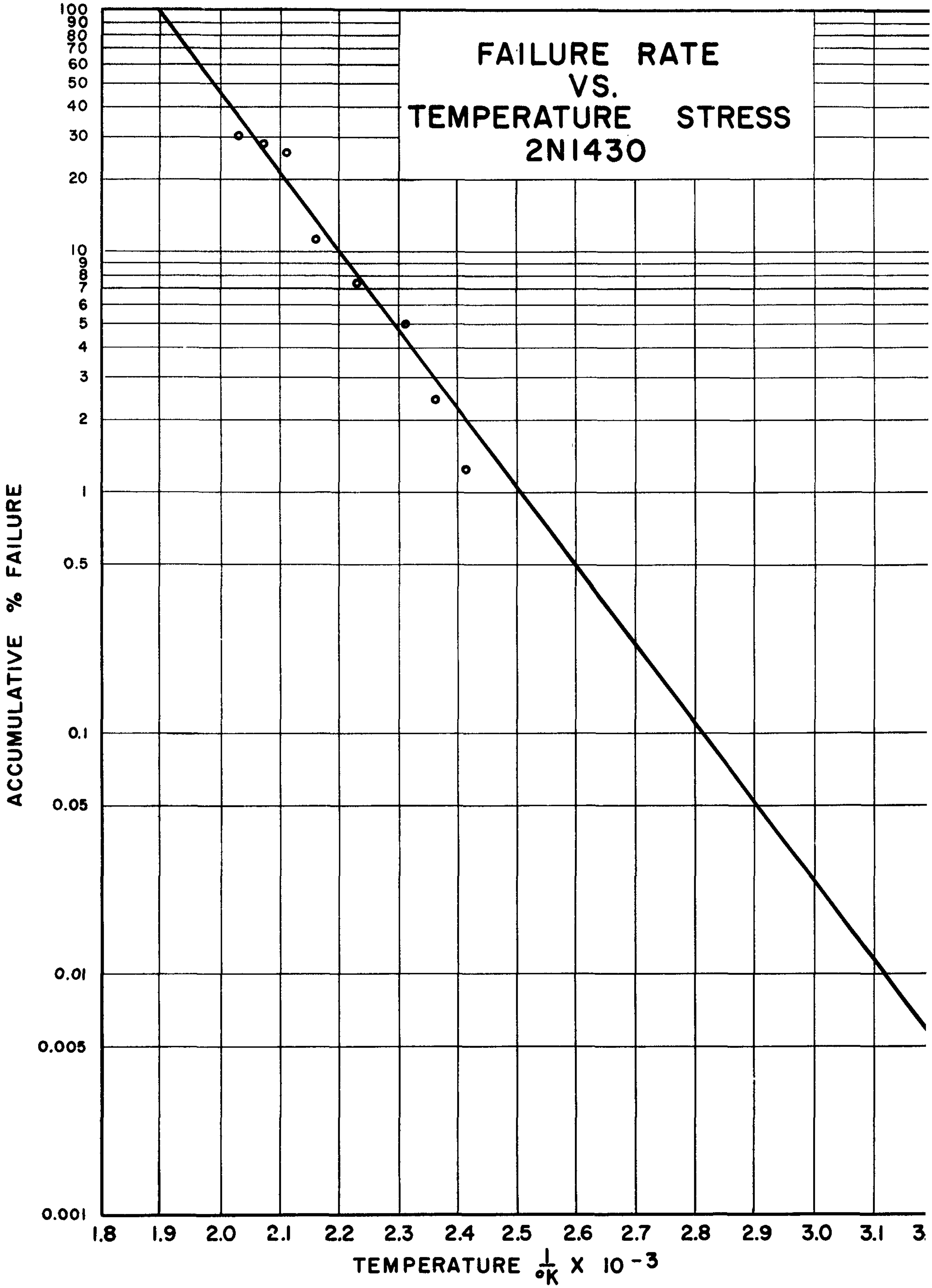
Units in CC He/sec.

V - APPENDIX I

Failure Rate Analysis

Temperature step-stress data is included as Appendix I. This testing was performed on 2N1430 transistors taken from a recent production lot.

The twelve (12) sample units submitted during this period, as per contractual requirement, were from the same lot.



FAILURE RATE
VS.
TEMPERATURE STRESS
2N1430
ACCUMULATIVE % FAILURE
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0.5
0.1
0.05
0.01
0.005
0.001
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3.0
3.1
TEMPERATURE $\frac{1}{°K}$ X 10^{-3}